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Spin Structure Functions at SLAC E142/E143 Experiments

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1. Introduction

In 1988 EMC collaboration (CERN) reported on an measurement for the proton spin structure function $g_1^p(x)$ [1]. This experiment gave a new interest in the field of spin physics because the results were surprising. The disagreement between the Ellis-Jaffe sum rule prediction for $\int_0^1 g_1^p(x)dx$, and the measurement was at the level of 2.5 standard deviation. This implied that the quark were carrying little or none of the spin of the nucleon. This last point became known as the spin crisis and generated a tremendous amount of papers in the field.

A second generation of experiment was planned (SMC at CERN, and E142,E143 at SLAC) to test the Bjorken sum rule, and check EMC results.

2. experiment E142

E142 took place at Stanford Linear Accelator (SLAC) in Automn 1992. It is an inclusive deep inelastic experiment using a polarized electron beam scattering off a polarized ^3He target [2].

The principle consist in measuring the difference between the scattering cross sections for the e^- helicity parallel and antiparallel to the target helicity. Scattering off an He^3 target is essentially similar to scattering off a polarized neutron and two unpolarized protons. Because of the Pauli exclusion principle the two protons have opposite spins and thus, cancel each other. In fact there is more than this S state in the ^3He wave function and some peoples [3],[4] showed that, the neutron carries about 87 % of the ^3He spin., thus an ^3He target can be viewed as a good polarized neutron target.

The E142 spectrometer was built as two single arms, one at scattering angle of 4.5^0, and the other at 7.0^0. The two arms set-up gives a good x and Q^2 coverage, the small angles (4.5 and 7.0) are necessary for providing the low x data and sufficient statistics. The mean Q^2 was 2 GeV^2 while the x range was between 0.03 and 0.6.

The E142 polarized e^- source delivered a 40 % polarized beam, and the target polarization was about 38% during the course of the experiment.

In order to eliminate false asymetries, the helicity of the incoming beam was reversed pseudo-randomly on a pulse by pulse basis whereas the target helicity was reversed twice a day.

There is a direct relationship between the assymetry $A_{||}$ defined as

$$A_{||} = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} \quad (1)$$

$$= D.(A_1 + \eta A_2) \quad (2)$$

and $g_1(x)$ [5]. D and η are kinematical factors. From the measurement of $A_{||}$, it is possible to extract the asymmetry $A_1(x)$, and then, get $g_1(x)$.

There is a term depending on $A_2(x)$ in (2). $A_2(x)$ is the transverse spin asymmetry and it has either been neglected (because η is a very small factor), or estimated with the positivity bound $|A_2(x)| < \sqrt{R}$ in previous experiments.

The determination of $A_\perp$ (target spin is perpendicular to the incoming e^-), give access to $A_2(x)$, ans so to the second structure function $g_2(x)$.

In E142, a value was obtained for $A_2(x)$. Even, with this crude determination, it was possible to see that the positivity constraint was respected. The upper bound obtained on $A_2(x)$ was used in (2) to extract $A_1(x)$.

When extracting any structure function one must take in account the following corrections :

- Nuclear effects, because the neutron is bound into the He^3 nucleus,
- QED radiative corrections,
- QCD radiatives corrections,
- Higher twist terms.

3. QED radiative corrections

The radiative corrections were calculated using [6]. It is a rather involved procedure because one must either work iteratively or use a model dependant polarized cross-section. Some general comments about these corrections can be made.

Even if the correction is significant on the cross-section, it is smaller on the asymmetries because it cancels partially in the substraction.

The dominant contribution comes from bremsstrahlung diagrams. An accurate determination of the elastic and resonances contributions is crucial.

The statistical error on the asymmetry will be changed by the correction. Specifically, it will increase at low x, because the radiative corrections move events from high x to low x. So when substracting radiative events from the low x bins the error bar increases.

4. QCD radiative corrections

The deep inelastic scattering process, is described by the hadronic tensor defined as

$$W_{\mu\nu} = \int_0^1 d^4 z e^{iqz} < N|J_\mu(z)J_\nu(0)|N > \quad (3)$$

This tensor is also written covariantly in terms of invariant 4-vectors p, q (for the proton and the virtual photon respectively) and structure functions.

Using standard techniques such as O.P.E. [7], the matrix current element in (3), is expanded in a sum of composite operators times Wilson coefficients.

The Ellis-Jaffe sum rule can be derived from this, and reads :

$$\int_0^1 g_1^n(x)dx = \frac{\Delta\Sigma}{9} + (-\frac{a_3}{12} + \frac{a_8}{36}) \quad (4)$$

There are two parts in this expression. The first one is the singlet part and contains the spin dependance. The second one is the non-singlet part and is expressed as a combination of current matrix elements.

These matrix elements (a_3 and a_8) are measured in other experiments like hyperons decays, and are well known. Thus, measuring the first moment of the $g_1(x)$ structure function, and knowing the non-singlet part, one can extract the singlet part and therefore the value $\Delta\Sigma$ for total spin of the nucleon carried by the quarks.

The QCD radiative corrections were computed up to the third order for the non-singlet part [8] and second order for the singlet one [9].

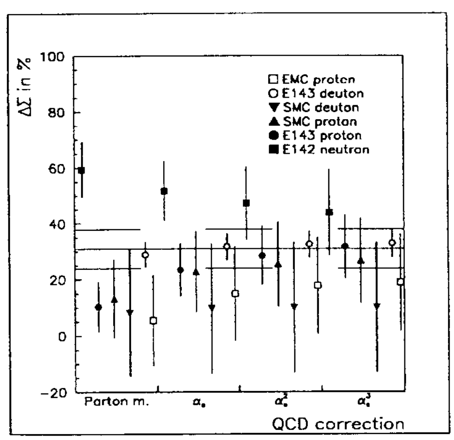

Figure 1. QCD corrections on $\Delta\Sigma$

Figure 4 shows the value of the $\Delta\Sigma$, extracted from available deep inelastic experiments. As we can see, it is a very important effect and brings every experiment in good agreement towards a value of $\Delta\Sigma = 0.31 \pm 0.10$ (world average).

5. Higher twist

Higher twist terms are higher order corrections to the cross-section behaving as powers of $\frac{1}{Q^n}$. They are suppressed at Q^2 big enough, but in the case of E142 this as been questionned (the mean Q^2 is only 2 GeV^2). Several groups [10],[11],[12] tried to estimate HT effects. It seems now that they agree to say that HT is small on the neutron and significant on the proton. For example, [10] quotes:

$$\begin{aligned} \int_0^1 g_1^{n(p)}(x)dx &= LT + \frac{a_{n(p)}}{Q^2} \qquad (5) \\ a_n &= 0.000 \pm 0.030 \qquad (6) \\ a_p &= -0.090 \pm 0.06 \qquad (7) \end{aligned}$$

It is difficult to measure HT terms directly. Nevertheless, one can estimate them indirectly by using together first and second moments of $g_1(x)$ and $g_2(x)$ structure functions [13]. This approach will be tried as soon as there will be accurate measurement of $g_2(x)$.

6. conclusion

There is now a good agreement between experiments regarding the value $\Delta\Sigma$ for the fraction of the nucleon spin carried by the quarks. The world average is $\Delta\Sigma = 0.31 \pm 0.10$, far from the expected parton model value $\Delta\Sigma = 0.60$. Thus, there is still a spin crisis, also some people claim that they have solved it [14]. In the future, two important results are needed. Namely, an accurate measurement of $g_2(x)$ which will allow the study of higher twists and experiments probing the gluon structure function going one step further in this spin crisis problem.

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